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Jambon, A; Barrat, J. A.; Bollinger, C.; Sautter, V.; Boudouma, O.; Greenwood, R. C.; Franchi, I. and Badia, D. (2010). Northwest Africa 5790. Top Sequence of the Nakhlite Pile. In: 41st Lunar and Planetary Science Conference, 1-5 Mar 2010, Houston, Texas.

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Version: Accepted Manuscript

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NORTHWEST AFRICA 5790. TOP SEQUENCE OF THE NAKHLITE PILE. A. Jambon¹ J-A. Barrat^{2,3}, C. Bollinger^{2,3}, V. Sautter⁴, O. Boudouma¹, R.C. Greenwood⁵, I.A. Franchi⁵ and D. Badia¹, ¹UPMC Univ Paris 06, ISTEP CNRS-UMR 7193, Paris France albert.jambon@upmc.fr, ²Université Européenne de Bretagne, ³Université de Brest CNRS-UMR 6538 IUEM, 29280 Plouzané France, ⁴MNHN Paris, Laboratoire de Minéralogie et Cosmo-chimie, CNRS-UMR 7202, Paris France, ⁵PSSRI, The Open University, Walton Hall, Milton Keynes MK7 6AA, UK.

Introduction: Northwest Africa (NWA) 5790 is the eighth nakhlite, found in the Sahara (Mauritania?) by nomads and purchased in Erfoud (Morocco). As will be seen below it is not paired with any previous find. Dating is reported elsewhere [1]

Petrography: The texture is one of a lava (Fig.1) with dominant millimetric euhedral augite (51%) irregularly zoned in their cores and sharply rimmed. Other phenocrysts are subsidiary euhedral olivine (9%) of slightly larger size, steadily zoned to their core and rare titanomagnetite (<1%). Abundant mesostasis (40%) contains dendritic crystals of oxides, calcic pyroxene, fayalitic olivine, two feldspars, silica, merrillite, Cl-apatite and glass. Minor Cl-amphibole is trapped in melt inclusions. The texture (Fig 1) strongly recalls NWA 817 or MIL 03346 [2-4].

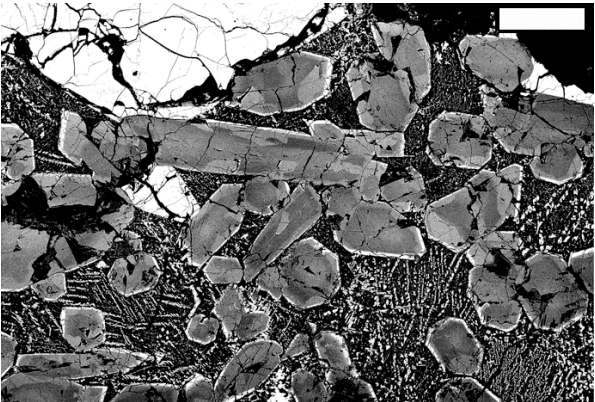


Fig. 1: BSE picture. Scale bar 0.5 mm

Mineral compositions: augite phenocrysts exhibit a MgO depleted core (En₃₅–Fs₂₄ Wo₄₀ and Fe/Mn = 32), patchy zoning and a sharp rim (En₂₀Fs₄₃Wo₃₆ and Fe/Mn= 42) (Fig 1-3) on the order of 20 micrometers. Olivine are steadily zoned from their core (Fa₆₅ with Fe/Mn = 47) to their rim (Fa₈₀ with Fe/Mn = 40) (Fig 2). Ti-magnetite phenocrysts Uv₃₂Mt₅₆-Sp₇Ct₄ exhibit fine ilmenite exsolutions. In the mesostasis dendritic crystals of Ti-magnetite are Al and Cr free Uv₅₂₋₇₄Mt₃₈₋₁₉, acicular pyroxene En₇Fs₄₇Wo₄₆ and Fe/Mn = 55, enriched in aluminum (Tschermak component) and olivine Fa₇₈₋₈₈ are observed. Plagioclase An₂₀Ab₇₁Or₉ and K-feldspar An₂Ab₁₇Or₈₁ on average, are strongly zoned. The major elements of mesostasis were analyzed by EPM in scanning mode over areas of 0.20x0.15 mm² and

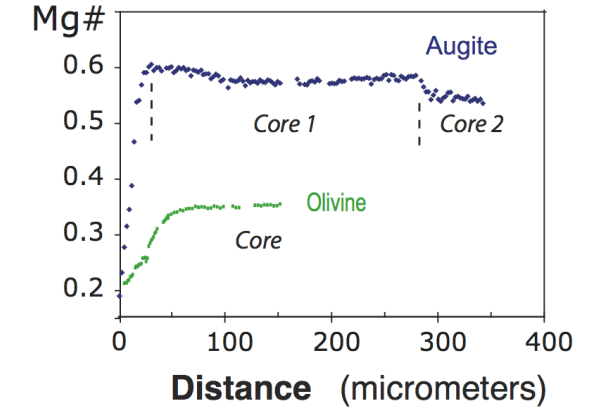


Figure 2. Zoning of olivine and augite.

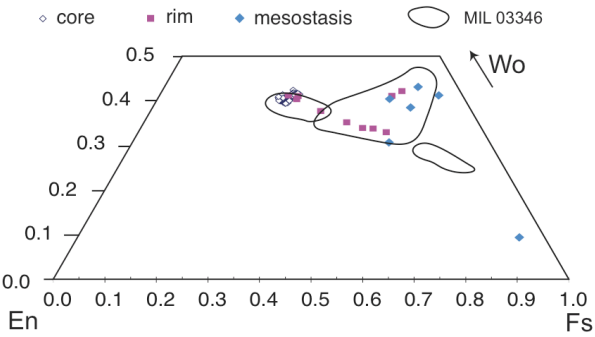


Fig. 3. Pyroxene compositions compared to MIL's [3]

	NWA		MIL 03346	
	5790	error		Error
SiO ₂	54.80	0.20	52.49	0.97
Al ₂ O ₃	14.33	0.09	13.89	0.31
MgO	0.44	0.01	0.42	0.04
FeO	17.13	0.27	16.73	1.17
MnO	0.26	0.01	0.24	0.02
CaO	4.25	0.07	4.00	0.16
Na ₂ O	5.40	0.04	5.22	0.11
K ₂ O	1.10	0.02	1.03	0.05
TiO ₂	0.81	0.01	0.82	0.14
Cr ₂ O ₃	0.00	0.00	0.00	0.00
P ₂ O ₅	0.96	0.05	0.83	0.04
Total	99.50	0.07	95.67	0.67

Table 1 : Mesostasis composition compared to MIL's

compared to the mesostasis of MIL 03346 measured under similar conditions.

Geochemistry: The oxygen isotope composition of NWA 5790 was determined by laser fluorination [5]. Two distinct fractions were hand picked from the meteorite, one olivine-rich and the other a “grey” mesostasis-rich fraction. The oxygen isotope composition of the olivine-rich fraction is: $\delta^{17}\text{O} = 2.55\text{‰}$; $\delta^{18}\text{O} = 4.32\text{‰}$; $\Delta^{17}\text{O} = 0.28\text{‰}$ and the “grey” mesostasis-rich fraction: $\delta^{17}\text{O} = 3.22\text{‰}$; $\delta^{18}\text{O} = 5.61\text{‰}$; $\Delta^{17}\text{O} = 0.28\text{‰}$ (all $\Delta^{17}\text{O}$ values are linearised [6]). The $\Delta^{17}\text{O}$ values of both fractions are within error of the Mars Mass Fractionation Line [7] (Fig. 4), thus confirming the Martian origin of NWA 5790. The relatively large difference in $\delta^{18}\text{O}$ values between the two fractions is consistent with their mineralogy i.e. one being olivine-rich and the other mesostasis-rich.

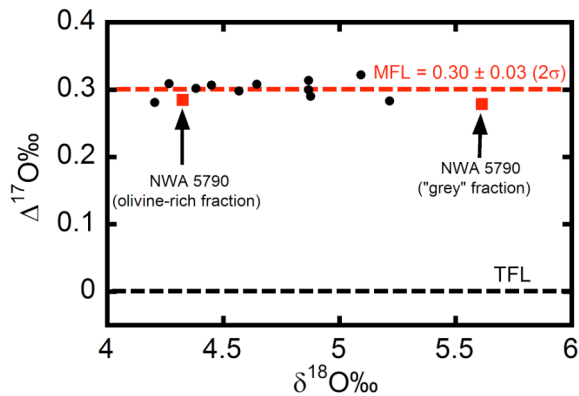


Fig. 4. Oxygen isotope composition of NWA 5790

Bulk major-element chemistry reflects the abundance of mesostasis: $\text{MgO} = 8.0\%$, $\text{Al}_2\text{O}_3 = 5.3\%$, instead of 11.8% and 1.6% for Nakhla. Element ratios however confirm unambiguously the Martian origin ($\text{FeO}^*/\text{MnO} = 38$, $\text{Na}_2\text{O}/\text{Al}_2\text{O}_3 = 0.39$, $\text{K}/\text{La} = 476$, $\text{Ga}/\text{Al} = 3.5 \cdot 10^{-4}$). NWA 5790 displays the highest Th, U and rare earth elements (REE) abundances ever reported for a nakhlite (e.g., $\text{Th} = 0.85 \text{ ppm}$); the REE pattern (figure 5) is characterized by a strong light

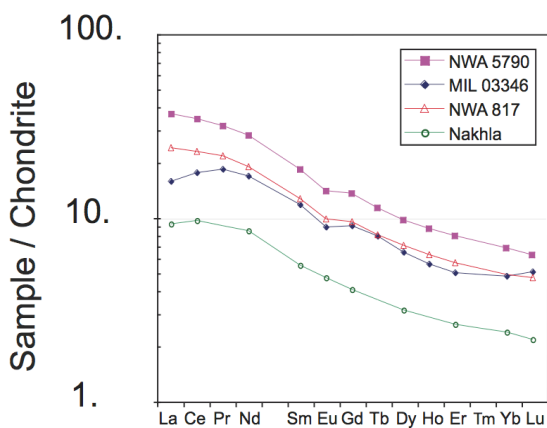


Fig. 5: REE patterns of nakhlites compared [3,4,8].

REE enrichment: $(\text{La}/\text{Yb})_n = 5.5$, and $\text{Eu}/\text{Eu}^* = 0.86$. Trace element compositions (24 elements) of augite, olivine and mesostasis were obtained by laser ablation ICP-MS (figure 6).

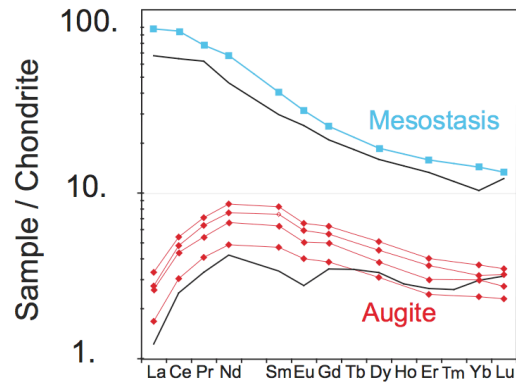


Fig. 6. REE pattern of separate phases compared to MIL 03346 (full lines) [3].

Discussion: According to its texture, mineralogy, chemical and isotopic composition NWA 5790 is a Martian meteorite of the nakhlite group. Augite phenocrysts do preserve complex primary zoning not observed so far in any of the other nakhlites. This indicates a fast cooling rate precluding chemical homogenization. The presence of Cl-rich amphibole suggests localized contamination by small debris of Cl-rich sediments, as previously reported for MIL 03346 [10]. Compared to other nakhlites its characteristic is the abundance of mesostasis which is reflected in the overall chemical composition. In addition to its abundance, the mesostasis is also more evolved, as indicated by the trace element abundances (fig.5-6, table 1) [2-4,8,9]; the composition of the whole rock indicates a large fraction of intercumulus liquid. This latter is out of equilibrium with the phenocrysts, and augite and olivine are not in equilibrium either. We can therefore suggest that NWA 5790 represents the topmost section of a lava pile [11] with a higher quenching rate and less compaction. The more evolved composition however suggests a zoned magma chamber.

References: [1] Shih C.-Y. et al. (2009) this vol. [2] Treiman A. H. (2005) *Chem. Erde*, 65, 203-270. [3] Day J.M.D. et al. (2006) *MPS* 41, 581-606. [4] Sautter V. et al. (2002) *EPSL* 195, 223-238. [5] Miller M.F. et al. (1999) *Rapid Commun. Mass Spectrom.* 13,1211-1277. [6] Miller M.F. (2002) *GCA*, 66, 1881-1889. [7] Franchi I.A. et al. (1999) *MAPS* 34, 657-661. [8] Nakamura N. et al. (1982) *GCA* 46, 1555-1573. [9] Wadhwa, et al., (2004) *Antarct. Meteorite Res.* 17, 97-116. [10] Sautter V. et al. (2006) *EPSL* 252,45-55 [11] Mikouchi T. et al. (2005) *LPS XXXVI*, CD-ROM #1944.